

PISTON TEMPERATURE  
MEASUREMENT AND PISTON  
DESIGN INVESTIGATION  
ON A C. F. R. ENGINE

BY  
N. O. WITTMANN  
J. H. SMITH, JR.

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PISTON TEMPERATURE MEASUREMENT

AND

PISTON DESIGN INVESTIGATION  
ON A C.F.R. ENGINE

By

Submitted by  
Lt. Com. N.O. Wittmann (USN)  
Massachusetts Institute of Technology,  
Cambridge, Massachusetts, and

Dear Professor Lt. Com. J.H. Smith, Jr. (USN)

Submitted in Partial Fulfillment of the  
Requirements for the Degree of

MASTER OF SCIENCE

This thesis is submitted from the  
Massachusetts Institute of Technology  
Aeronautical Engineering June 1946

Thesis  
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Cambridge, Massachusetts

June 1, 1946

Professor G. W. Swett, Executive Laboratory, Massachusetts  
Secretary of the Faculty,  
Massachusetts Institute of Technology, March 1, 1946  
Cambridge, Massachusetts.

Dear Professor Swett:

We submit herewith, a thesis entitled "Piston  
Temperature Measurement and Piston Design Investigation  
on a C.F.R. Engine".

This thesis is submitted in partial fulfillment of  
the requirements for the degree of Master of Science in  
Aeronautical Engineering.

Respectfully submitted,

1948

RECEIVED

Massachusetts Institute of Technology

June 1, 1948

Professor C. W. Smith  
Secretary of the Society  
Massachusetts Institute of Technology  
Cambridge, Massachusetts

Dear Professor Smith:

We submit herewith a thesis entitled "The  
Thermodynamic Properties of the  
on a C.V.M. Basis".

This thesis is submitted in partial fulfillment of  
the requirements for the degree of Master of Science in  
Chemical Engineering.

## ACKNOWLEDGMENT

The investigation reported in this thesis was conducted in the Sloan Automotive Laboratory, Massachusetts Institute of Technology, over the period March 1, 1946 to June 1, 1946.

Acknowledgment of, and appreciation for, assistance in this thesis is given to the following sources:

Professor J. A. Leary (M.I.T. Staff)

Pratt and Whitney Aircraft, East Hartford, Conn.

Mr. J. C. Livengood (M.I.T. Staff)

Mr. E. Gagger

The mechanics and assistants of the Sloan Laboratory.

Any opinions or statements contained herein represent the private views of the authors, and are not to be construed as official or in any sense reflecting those of the Navy and the naval service.

The investigation reported in this bulletin was conducted in the High Altitude Laboratory, Montezuma, New Mexico, over the period from June 1, 1964, to June 1, 1965.

the Navy and the naval service, witness as official is in my name testifying about the private view of the witness, and the fact is not any opinion or statement made by the witness.



## PREFACE

mechanical difficulties. They were an attempt to invent

The purposes of this investigation were twofold:

1. To construct a satisfactory arrangement for the measurement of piston crown temperature in a C. F. R. Engine.
2. To determine the effect of piston crown design on piston temperature, with and without a forced system of cooling on the inside of the piston.

The subject was chosen for its particular interest to the authors in view of the considerable amount of piston "scouring" in present day engines of high speed and power. So much time has been spent on cylinder head design and so relatively little on interior piston design that it was thought advisable to attempt to find some of the trends occurring with changes in the design of the piston crown interior, and to note the effect of changes in some engine operating variables on piston crown temperatures.

T. Yamamoto and H. Nakamura ("Effect of Changes in Design and Operating Conditions on Cooling" M.I.T., 1935) attempted to measure piston temperatures on a C.F.R. engine and note the change of piston temperature with changes in crown thickness but were not highly successful due to

PHASE

The purpose of this investigation was twofold:

1. To determine a satisfactory arrangement for the measurement of piston crown temperatures in a

W. E. A. engine.

2. To determine the effect of piston crown cooling

on piston temperature, with and without a forced

system of cooling in the form of the piston.

The subject was chosen for the following reasons:

In the subject is view of the considerable amount of the

the "combustion" in engines and engines of this type and

power. It was found that the piston crown was

also one of the most difficult parts to inspect when engine

was in use. It was found that it was difficult to find out

the piston crown temperature in the case of the

piston crown temperature, and to find the effect of the

it was found that the piston crown temperature was

variable.

2. It was found that the piston crown temperature is

variable and depends on many factors (W. E. A. engine)

It was found that the piston crown temperature was

variable and depends on many factors (W. E. A. engine)

It was found that the piston crown temperature was



mechanical difficulties. They made no attempt to investigate the effect on piston temperature of changes in interior piston crown design.

There is no doubt that the above is a true statement. The fact that the above is a true statement is not in doubt. The fact that the above is a true statement is not in doubt.

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Pictures and drawings of engine and component parts. Figures 1-3.

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Tables and Curve Sheets. Tables I, II, III, and Figures 9-16.

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I, \_\_\_\_\_  
do hereby certify that \_\_\_\_\_  
is the owner of \_\_\_\_\_  
situated in \_\_\_\_\_  
County of \_\_\_\_\_  
State of \_\_\_\_\_

Witness my hand and seal this \_\_\_\_\_ day of \_\_\_\_\_ 19\_\_\_\_.

Notary Public for the State of Texas.

My Comm. Expires \_\_\_\_\_

Notary Public

My Comm. Expires \_\_\_\_\_

Notary Public

PISTON TEMPERATURE MEASUREMENT  
AND  
PISTON DESIGN INVESTIGATION  
ON A C.F.R. ENGINE

By

Lt. Com. W. O. Wittmann (USN)

and

Lt. Com. J. H. Smith, Jr. (USN)

April - May 1946

**ACKNOWLEDGMENTS**

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PLATE 100

BRISBANE, N.S.W., 1980

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U.S. Gov. J. H. Easton, Jr. (1901)



## SUMMARY

A method of measuring piston temperature on a C.F.R. engine under operating conditions was carried through with the following results noted:

1. The method of piston temperature measurements proved very satisfactory.
2. Finning on the inside of the piston crown causes the piston to run hotter than with no finning.
3. A stream of oil under pressure applied to the under side of the piston crown lowers the piston temperature considerably, and is much more effective on a piston with deep fins on the inside of the crown than on one with no fins.
4. Piston temperatures tend to increase with an increase of engine speed.
5. Piston temperatures tend to increase with an increase of water jacket temperature.
6. Piston temperatures are highest as the fuel air ratio approaches that of best power, and drop off rapidly as the mixture is made leaner or richer than this value.
7. Inlet temperature has little effect on piston temperature.
8. Indications on one run tended to show that "blow by", caused by damaged piston rings, caused piston temperatures to be higher until rings were "worn in", indicating that a portion of the heat transfer from the piston goes to the cylinder walls via the rings.

# NOTES

A method of measuring piston temperature on a 0.5-2. engine under

operating conditions was carried through at the following results

noted:

1. The method of piston temperature measurement proved very satisfactory.
2. Placing on the inside of the piston crown caused the plates to run hotter than at the outside.
3. A stream of oil under pressure applied to the outer side of the piston crown lowers the piston temperature considerably, and is much more effective on a piston with deep than on the inside of the crown than on one with no ring.
4. Piston temperatures tend to increase with an increase of engine speed.
5. Piston temperatures tend to increase with an increase of water jacket temperature.
6. Piston temperatures are highest on the first six rings especially that of base power, and drop off rapidly as the distance is made lower on which this value.
7. Inlet temperature has little effect on piston temperatures.
8. Induction air can be heated to over 200° F., caused by damaged piston rings, caused piston temperatures to be higher until rings were worn in, following which a portion of the heat flows from the piston back to the cylinder walls at the rings.

There is a considerable amount of investigation to be done in this field and it provides an excellent opportunity for future students to study other phases of this subject. The working system has already been constructed, they need only investigate.

All tests were made in the Sloan Automotive Laboratory of the Massachusetts Institute of Technology by Lt. Com. N. O. Wittmann, USN, and Lt. Com. J. H. Smith, Jr., USN, under the direction of Prof. W. A. Leary of the school staff.



There is a considerable amount of investigation to be done in this

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study other phases of this subject. The writer wishes to already have  
completed, they need only investigate.

All tests were made in the Ohio Industrial Laboratory of the  
Bureau of Industrial Hygiene of Technology by Dr. C. E. Williams, M.D.,  
and Dr. C. E. Smith, Jr., M.D., under the direction of Prof. W. A.  
Leary of the school staff.

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the reaction between a certain substance and a certain substance.

## PISTON TEMPERATURE MEASUREMENT AND PISTON DESIGN INVESTIGATION ON A C.F.R. ENGINE.

### INTRODUCTION

Although there have been investigations made on piston temperatures, there has been little successful work along these lines attempted in this laboratory. This project has been a necessarily hastened attempt to get some satisfactory results from the measurement of piston temperature in a standard C.F.R. engine under operating conditions.

Briefly, the objects of this project were:

1. To set up a satisfactory system of measuring piston temperatures in a C.F.R. engine under operating conditions.
2. To measure the piston head temperature of three different types of pistons and note how their designs affected cooling.
3. To determine the cooling effect of a stream of oil on the lower side of the crown of each piston.
4. To determine the effect on piston temperature of changes in some of the engine operating variables.

All tests were made in the Sloan Automotive Laboratory of the Massachusetts Institute of Technology by Lt. Com. H. O. Wittmann, USN, and Lt. Com. J. H. Smith, Jr., USN, under the direction of Prof. W. A. Leary of the school staff.

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## 1977-1978, 1981-1982

Although there have been investigations with an object temperature, there has been little successful work along these lines reported in this laboratory. The project has been a measurably better attempt to get some satisfactory results from the measurement of glass temperature in a standard U.S.N. water under existing conditions.

... ..

1. The use of a specialized type of equipment to detect and identify the presence of a specific substance.

Figure 1. A schematic diagram of the experimental setup. The subject is seated in a chair and views the screen through a mirror. The screen displays the target and the starting position of the hand. The hand is moved from the starting position to the target position. The distance between the starting position and the target position is the reach distance. The distance between the starting position and the mirror is the viewing distance. The distance between the mirror and the target is the target distance. The distance between the starting position and the target is the reach distance. The distance between the starting position and the mirror is the viewing distance. The distance between the mirror and the target is the target distance.

2. To ensure the proper use of funds

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2. To determine the rolling effect of a vessel of all the

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It is requested that you advise the Bureau of the results of your investigation.

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All cases were held in the Essex Magistrate's Court.

Manuscript received July 1994; revised manuscript received May 1995; accepted for publication June 1995.

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## EQUIPMENT

A standard C.F.R. single cylinder, water cooled, variable compression ratio engine of 3.25 inch bore and 4.5 inch stroke was used. (Figures 1 and 2.)

The fuel air inlet system consisted of a puff tank and a vaporizing tank, the temperature of which was controlled by any desired combination of steam or cold water. The air supply came directly from the atmosphere through a measuring orifice. The pressure differential across the orifice was measured with a standard manometer, enabling the air flow to be computed exactly at all engine speeds and conditions. The fuel was metered through a calibrated rotometer which allowed any desired fuel air ratio to be set and held constant.

The exhaust system led through a puff tank around which cold water circulated. The exhaust pressure remained essentially constant at atmospheric pressure.

The spark was controlled by a breaker mechanism coupled directly to the crankshaft in order to hold a constant spark advance.

The cylinder jacket was water cooled and the temperature of the jacket could be maintained as desired by proper admittance of cold water or steam.

The power generated by the engine was absorbed by a dynamometer of the conventional cradle type. The speed could be accurately controlled by means of a variable field coil, tachometer, and strobetac operating on a 60 cycle frequency.

The engine oil temperature could be varied by the proper regulation of steam and cold water to the oil heat exchanger.

The three pistons used were essentially standard C.F.R. pistons with variations in design of the inside of the crown. All the pistons had the

# TESTIMONY

A standard 0.75 inch diameter, water cooled, vertical compressor  
with a piston of 3.5 inch bore and 4.5 inch stroke was used. (Exhibit I  
and J.)

The test air inlet system consisted of a 100 ft. hose and a regulating  
valve, the pressure of which was controlled by an aneroid manometer  
of known or solid water. The air supply came directly from the atmosphere  
through a breathing orifice. The pressure differential across the valve  
was measured with a standard manometer, recording the air flow as it  
passed directly at all engine speeds and conditions. The test was carried  
through a calibrated rotameter which allowed any desired test air flow  
to be set and held constant.

The exhaust system led through a 100 ft. hose which could either  
be exhausted. The exhaust pressure recorded essentially constant at atmo-  
spheric pressure.

The engine was controlled by a pressure mechanism which directly  
the movement of the piston in a constant speed engine.

The cylinder jacket was water cooled and the temperature of the jacket  
could be maintained as desired by means of a solid water of steam.

The power recorded by the engine was obtained by a pressure of  
the conventional crank type. The speed could be recorded by  
means of a variable field coil, tachometer, and synchronous generator as a  
50 cycle frequency.

The engine oil temperature could be varied by the proper regulation  
of steam and cold water to the oil heat exchanger.

The three pistons used were essentially identical 0.75 inch diameter with  
variations in design of the heads of the valves at the crown. All the pistons had the



same crown thickness and the same ring arrangement.

The first piston (termed the "plain piston") was a standard cast C.F.R. piston with no machining on the inside (Figures 3 and 4).

The second piston (termed the "ribbed piston") was a special casting with a grilled ribbing on the inside of the crown (Figure 5).

The third piston (termed the "finned piston") was another special casting with the deepest possible fins cast on the inside of the crown (Figures 6 and 7).

The iron constantan thermocouples were installed at a distance of  $1/32$  inch from the top of the piston and in the same relative position from the center of the piston,  $3/8$  inch from the center, laterally. The iron and constantan leads were brought down inside the piston to iron and constantan buttons on the lower edge of the piston skirt. These leads were held in place by small wire loops through drilled "V" holes in the piston wall. The thermocouples were installed in drilled holes approximately  $1/32$  inch in diameter, and were held in place with dental cement. The iron and constantan buttons in the edge of the piston skirt were installed in micarta blocks which were shrunk fit into drilled holes in the piston skirt. The entire system, except the actual faces of the contact points, was given several coatings of glyptol (Figures 3, 5 and 6).

The take off switch was mounted on a bracket and plate which was attached to the side of the crankcase after removal of one of the crankcase side plates. Elongated holes in the plate allowed for up and down adjustment to get proper contact of switch points with the contact points on the piston skirt.

The switches were constructed from magneto breaker points that were modified to give desired results. One switch required the addition of a

same from the glass and the same from the atmosphere.

The first piston (named the "glass piston") was a standard cast

C.V.R. piston with no machining on the inside (Figures 3 and 4).

The second piston (named the "rubber piston") was a special cast-

ing with a drilled ribbing on the inside of the crown (Figure 5).

The third piston (named the "fluted piston") was another special

casting with the deepest possible flutings on the inside of the crown

(Figures 6 and 7).

The iron constant thermocouples were located at a distance of

1/32 inch from the top of the piston and in the same relative position

from the center of the piston, 3/8 inch from the center, laterally. The

iron and constant thermocouples were brought down inside the piston to iron

and constant patterns on the lower edge of the piston skirt. These

leads were held in place by small wire loops through drilled "V" holes

in the piston wall. The thermocouples were located in drilled holes

approximately 1/32 inch in diameter, and were held in place with dental

cement. The iron and constant patterns in the edge of the piston skirt

were installed in master blocks which were struck by the drilled holes

in the piston skirt. The entire system, except the actual leads of the

constant points, was given several coatings of epoxy (Figures 8, 9 and 10).

The tail off section was mounted on a bracket and plate which was at-

tached to the side of the crankcase after removal of one of the crankcase

side plates. Electrical leads in the plate allowed for up and down adjust-

ment to get proper contact of switch points with the contact points on the

piston skirt.

The tail section was constructed from separate bracket parts that were

modified to give desired results. One section required the addition of a



constantan button to which a constantan lead wire was directly soldered. The other switch had an iron button attached to the spring, from which an iron wire was led. Both switches were insulated from each other and the bracket by bakelite. The whole assembly was covered with several coatings of glyptol (Figure 8). The switches could be adjusted laterally and vertically by set screws to match the piston skirt contacts and to contact simultaneously.

The iron and constantan leads were covered with plastic tubing and glyptol, to prevent entrance of moisture. They were led out through the switch plate to a direct reading Leeds and Northrup type potentiometer. The potentiometer was equipped with a special sensitive type of galvanometer with the following characteristics:

Resistance	17 ohms
Period	5 seconds
Sensitivity	0.66 A/MM

The potentiometer was located far enough from the engine to be free of all vibrations.

The oil stream for use on the under side of the piston was taken directly from the electrically driven engine oil pump, through the contact bracket plate, and into a nozzle formed from a piece of copper tubing. The oil was supplied at a rate of 17 lbs. per minute.

resistant bottom to which a suspension of lead shot was slowly released. The other which had no lead bottom attached to the spring, free with the shot when the lead shot was released from each side and the bottom of the bottle. The whole assembly was covered with several coatings of asphalt (Figure 3). The solution could be adjusted laterally and vertically by not moving to reach the bottom and contents and to contact the solution.

The iron and concrete parts were covered with lead shot and dipped in a solution of solution. They were laid out through the water plate to a glass vessel which had bottoming glass plates. The bottoming was adjusted to a point of equilibrium type of balance with the following characteristics:

Horizontal	Vertical
Fixed	Adjustable
1.5 cm	1.5 cm

The bottoming was located far enough from the spring so as to be of all adjustment.

The oil stream for use on the water side of the glass was taken

directly from the electrically driven engine oil pump through the non-ventilated place, and into a small bottle into a glass of oil.

oil. The oil was supplied at a rate of 15 lbs. per minute.



## PROCEDURE

All runs were made by setting the engine up at the desired running condition, loosening the take off switch bracket cap screws, raising the contact points until contact was evidenced on the potentiometer and then setting the contacts up approximately .02 inches further. It was found that this setting gave the most consistent results.

For each of the three pistons, the following runs were made:

1. Variation of water jacket temperature ( $90^{\circ}\text{F}$ ,  $150^{\circ}\text{F}$ ,  $210^{\circ}\text{F}$ ) for each of three different engine speeds (800, 1000 and 1200 rpms).
2. Same runs as above, but with a continuous stream of oil on the under side of the piston crown.
3. For the grilled piston, the following additional runs were made:

(a) Variation of fuel air ratio.

(b) Variation of fuel air inlet temperature.

Unless otherwise noted, the engine operating variables were kept at the following values:

Inlet temperature	$T_1$	$150^{\circ}\text{F}$
Water jacket temperature	$T_w$	$150^{\circ}\text{F}$
Crankcase oil temperature	$T_o$	$90^{\circ}\text{F}$
Engine oil pressure	$P_o$	$50 \text{ \#/in.}^2$
Engine fuel pressure	$P_f$	$10.7 \text{ \#/in.}^2$
Fuel air ratio	$F$	.08

## EXPERIMENT

All tests were made by running the engine up at the desired running condition, isolating the low oil relief circuit and valve, testing the contact points until contact was obtained on the potentiometer and then setting the contacts up approximately 10 inches further. It was found that this method gave the most consistent results.

For each of the three phases, the following tests were made:

1. Variation of water jacket temperature (90°F, 120°F, 150°F) for each of three different engine speeds (600, 1000 and 1800 rpm).
2. Same test as above, but with a continuous stream of oil on the under side of the piston crown.

3. For the fuel phase, the following additional tests were made:

(a) Variation of fuel air ratio.

(b) Variation of fuel air ratio temperature.

When operating under the engine operating conditions were kept

at the following values:

1	150°F	Water jacket temperature
2	120°F	Water jacket temperature
3	90°F	Water jacket temperature
4	30 W.A.T.	Engine fuel pressure
5	10.7 W.A.T.	Engine fuel pressure
6	0.8	Fuel air ratio

## RESULTS AND DISCUSSION

A tabulation of the results obtained for this project is given in Tables I, II and III.

This arrangement for the measurement of piston temperatures seemed to be entirely satisfactory. No part of the system gave mechanical trouble and once the arrangement was set up, no particular difficulty in measuring the temperature was encountered. All runs were checked as many times as possible and in all cases the results were in excellent agreement.

Contrary to what had been anticipated, the plain piston ran cooler than the ribbed piston, and the latter cooler than the finned piston. In Fig. 9 the effect of changes in engine speed on piston temperature can be seen. There is a general rise in piston temperature when engine speed is increased, with all other engine operating conditions held constant. It can be seen that the finned piston ran the hottest. Just why this is so is not definitely known, although it is suspected that the deep fins retard air circulation and oil splashing on the under side of the piston crown and thus more heat is retained by the crown, causing higher temperatures. Some of the difference in temperature may be due to the additional amount of piston material above the piston pin bosses in the plain piston, causing more heat to be carried away through this path, and consequently giving better cooling of the piston. However, the fact that the finned piston runs hotter than the ribbed piston of similar design and weight tends to discount this theory.

The forced system of carrying heat away proves very effective in all cases, and particularly so in the case of the finned piston. The final



# RESEARCH AND DEVELOPMENT

A detailed study of the results obtained for this project is given in

Tables I, II and III.

This investigation for the measurement of piston temperatures seemed

to be extremely satisfactory. The fact of the matter was somewhat

troubling and the arrangement was set up, on particular difficulty

in securing the temperature was satisfactory. All runs were checked as

many times as possible and in all cases the results were in excellent

agreement.

Consequently it was not necessary to make any further

than the above points, and the latter point was the limit piston.

In Fig. 3 the effect of change in engine speed on piston temperatures

can be seen. There is a marked rise in piston temperatures when engine

speed is increased, and in all other cases piston temperatures were

constant. It was also seen that the limit piston was the hottest. This

may be due to the fact that the limit piston is in contact with

the combustion chamber and all expansion in the cylinder

of the piston ring and some heat is retained by the crown, causing

higher temperatures. Some of the differences in temperatures may be due

to the different amount of piston material above the piston pin between

in the limit piston, causing some heat to be retained away from the

pin, and consequently higher temperatures of the piston. However,

one fact that the limit piston was hotter than the other pistons of

similar design and weight tends to discount this theory.

The forced system of cooling as used here was very effective in all

cases, and particularly so in the case of the limit piston. The limit

result is not as encouraging as was to be expected since the finned piston ran much hotter before the oil stream was applied. However, there are indications that some combination of deep finning plus forced heat removal may have possibilities in lowering the piston crown temperature and preventing scouring of pistons at present day high engine speeds and power.

Fig. 10 and Fig. 11 are repetitions of Fig. 9 at higher water jacket temperature and show the same trends.

Figs. 12, 13 and 14 show the variation of piston temperature with change in water jacket temperature at 800, 1000 and 1200 rpms respectively. Again, the finned piston runs hot and the plain piston cooler, until a forced oil stream is added and then the temperature trends are reversed. In general, the piston temperatures increase with increase in water jacket temperature, but the rate of increase is lowered as piston temperature is lowered.

Fig. 15 shows the effect of changes in fuel air ratio and inlet temperature on piston temperature. At very lean fuel air ratios, piston temperatures are low, but build up rapidly with an increase in fuel air ratio until approximately best power fuel air ratio is reached, at which point the temperatures reach their maximum, then drop off rapidly with further enrichening of fuel air ratio.

Changes of inlet temperature within the range of this setup gave little change in piston temperature.

Fig. 16 was an accidental occurrence that might well be investigated by future students. When the engine was started with new rings on the piston, "blow by" was indicated by a considerable amount of smoke coming



remains is not as unexpected as was to be expected since the fixed glass was much better than the other two. However, there are in-  
 dications that some modification of the design plus further work removal  
 may have possibilities in lowering the glass cover temperature and pre-  
 venting overheat of glass as shown by high surface temperature.  
 Fig. 10 and 11. It was suggested that the glass cover be made

longer and show the same results.  
 Fig. 12, 13 and 14 show the results of glass temperature with  
 change in water jacket temperature at 600, 1000 and 1500 rpm respectively.  
 In the fixed glass test and the plain glass test, with a  
 lower all around the glass and the temperature results are presented.  
 In general, the glass temperature results with jacket in water jacket  
 temperature, but the rate of increase is lower in glass temperature in  
 lower.

Fig. 15 shows the effect of change in jacket air rate and jacket tem-  
 perature on glass temperature. It was found that the glass tem-  
 perature was low, but still as high as the jacket in fact the  
 results were approximately the same. It was found that the  
 jacket the temperature was high, then drop in jacket air rate  
 lower condition of low air rate.

Change of glass temperature when the jacket air rate was  
 little change in glass temperature.  
 Fig. 16 was an additional experiment that was run to determine  
 the effect of jacket air rate. The jacket air rate was changed in the  
 jacket, which was followed by a considerable amount of water cooling



through the crankcase breather pipe. Also, piston temperatures were considerably higher than on all previous runs starting under the same conditions but with no apparent "blow by". As the time after starting increased, the smoke gradually decreased and piston temperatures lowered, until after about six hours of running, the temperatures were constant and agreed with previous runs; and the smoke from the breather ceased. It is thought that these new rings may have been scratched or were in some other way irregular, allowing "blow by" until they were properly "worn in". The "blow by" prevented the usual amount of heat transfer between the piston, piston ring, and cylinder walls, and caused higher piston temperatures until the point was reached where the rings were "worn in", no "blow by" occurred, and normal heat transfer to the cylinder walls took place.

It is suggested that further investigation along these lines could profitably be made by future students. The actual set-up is now completed and another group would not have to spend a considerable portion of their limited time in repeating what has already been accomplished, and could devote all of their time to more thorough and complete investigation of actual piston designs. It is further suggested that the plain piston should be machined on the under side of the crown to the same dimensions as the other two pistons and that perhaps another piston with slightly shorter fins could be investigated. Other subjects for investigation would be the use of a stream of compressed air on the under side of the piston crown, and a check on the effects of "blow by" on piston temperatures.

through the various positions. The first position was  
 immediately higher than the second and the third  
 position was also at a higher level. As for the other  
 positions, the whole gradually descended and the positions  
 were still about the same of course. The positions were  
 and the second was the lowest. The positions were  
 It is thought that there are things which have been  
 some other way. The positions, however, were  
 were in. The positions were the same as the first  
 between the first, second, and third positions, and  
 glass positions were still the same as the first  
 were in, as before, and the positions were the same  
 as before.

It is suggested that the positions were the same  
 possibly in the first position. The positions were  
 first and second positions were not the same as the  
 of their first position in the first position.  
 and would have all at the first position and the  
 position of the first position. It is suggested that the  
 position should be examined on the first side of the  
 position as the first position and the second position  
 although the first position could be the first  
 position would be the one of the first position and the  
 of the first position, and a second position of the  
 position.

## CONCLUSIONS AND RECOMMENDATIONS

The following conclusions were arrived at as the result of this investigation:

1. The method of piston temperature measurement used proved very satisfactory.
2. Finning on the inside of the piston crown causes the piston to run hotter than with no finning.
3. A stream of oil under pressure applied to the under side of the piston crown lowers the piston temperature considerably, and is much more effective on a piston with deep fins on the inside of the crown than on one with no fins.
4. Piston temperatures tend to increase with an increase of engine speed.
5. Piston temperatures tend to increase with an increase of water jacket temperature.
6. Piston temperatures are highest as the fuel air ratio approaches that of best power, and drop off rapidly as the mixture is made leaner or richer than this value.
7. Inlet temperature has little effect on piston temperature.



The following amendments were proposed to the  
 report of the Commission:

1. The Commission should be authorized to

investigate the following:

a. The Commission should be authorized to

investigate the following:

b. The Commission should be authorized to

investigate the following:

c. The Commission should be authorized to

investigate the following:

d. The Commission should be authorized to

investigate the following:

e. The Commission should be authorized to

investigate the following:

f. The Commission should be authorized to

investigate the following:

g. The Commission should be authorized to

investigate the following:

h. The Commission should be authorized to

investigate the following:

i. The Commission should be authorized to

investigate the following:

j. The Commission should be authorized to



8. Indications on one run tended to show that "blow by", caused by damaged piston rings caused piston temperatures to be higher until rings were "worn in", indicating that a portion of the heat transfer from the piston goes to the cylinder walls via the rings.

The following recommendations are made as suggestions for future study:

1. More intensive investigation of the three piston designs used for this project, with the "plain piston" machined under the crown to the wall dimensions of the other pistons.
2. Investigation of pistons of other designs, particularly with fin length between that of the "ribbed piston" and that of the finned piston.
3. Investigation of the use of compressed air on the under side of the piston crown to produce forced cooling.
4. Investigation of the effects of "blow by" on piston temperature.
5. Investigation of the heat flow through the piston crown by putting a number of thermocouples in the crown and upper ring "lands".



APPENDIX A





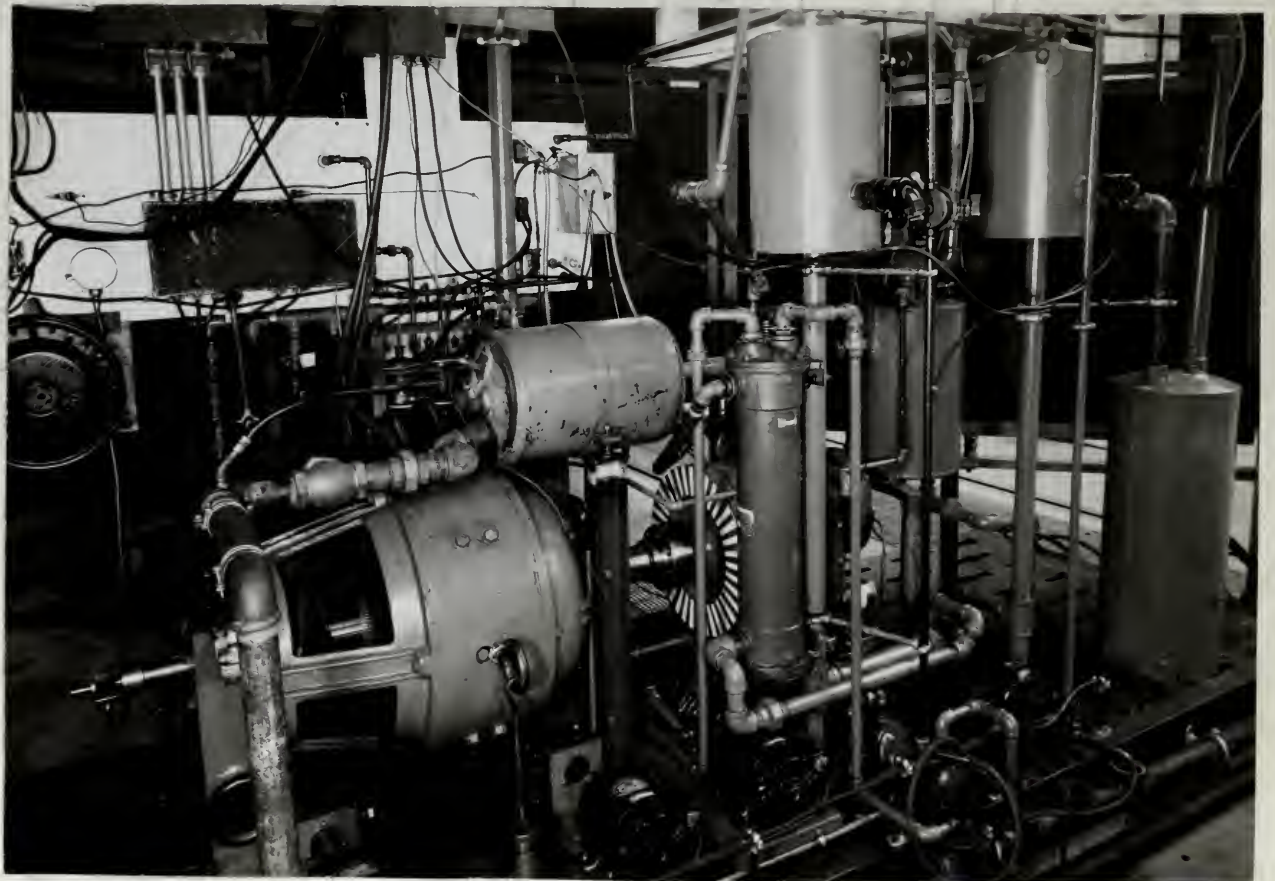
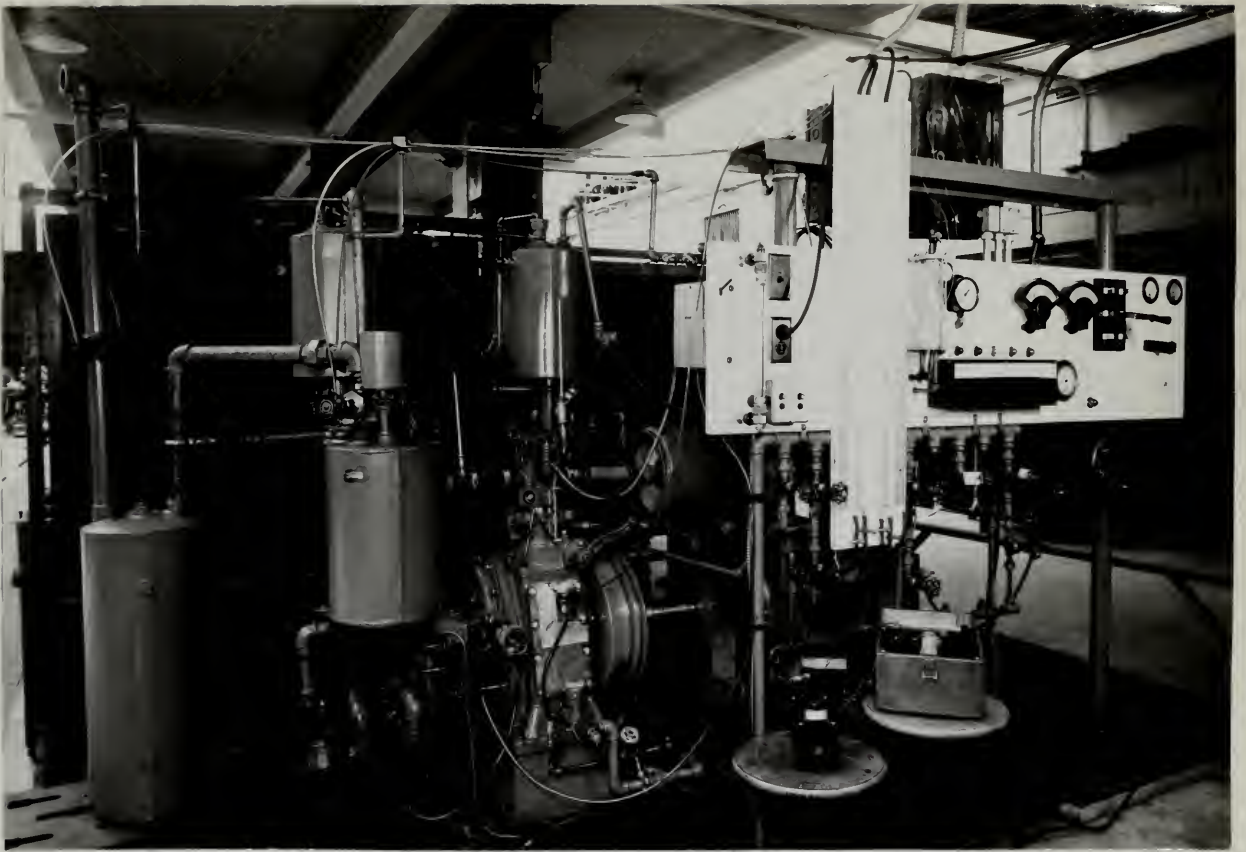


FIG. 1  
ENGINE LAYOUT

ENGINE LAYOUT  
FIG. 1

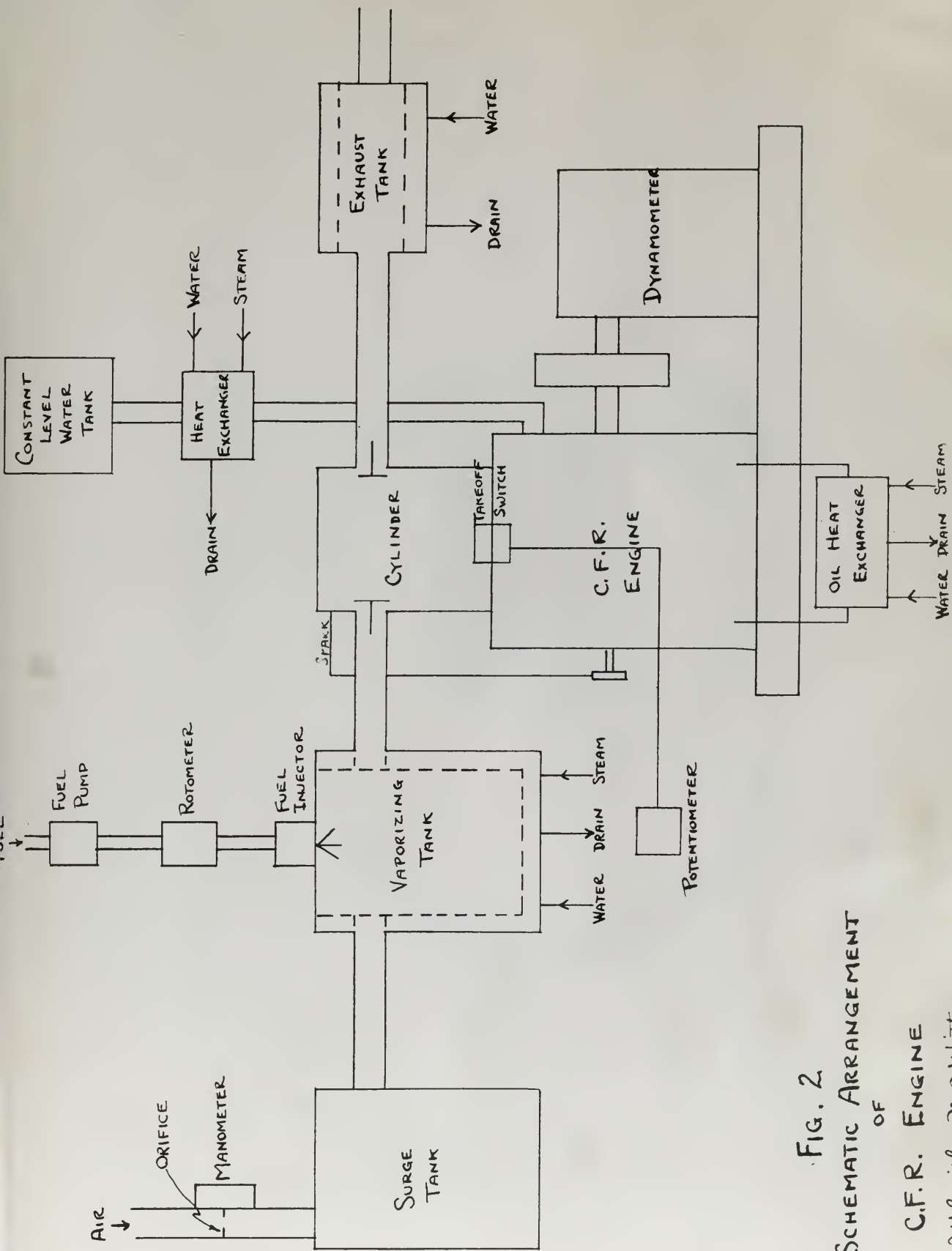


FIG. 2  
SCHEMATIC ARRANGEMENT  
OF

C.F.R. ENGINE

W. Smith - N.O. Wittmann

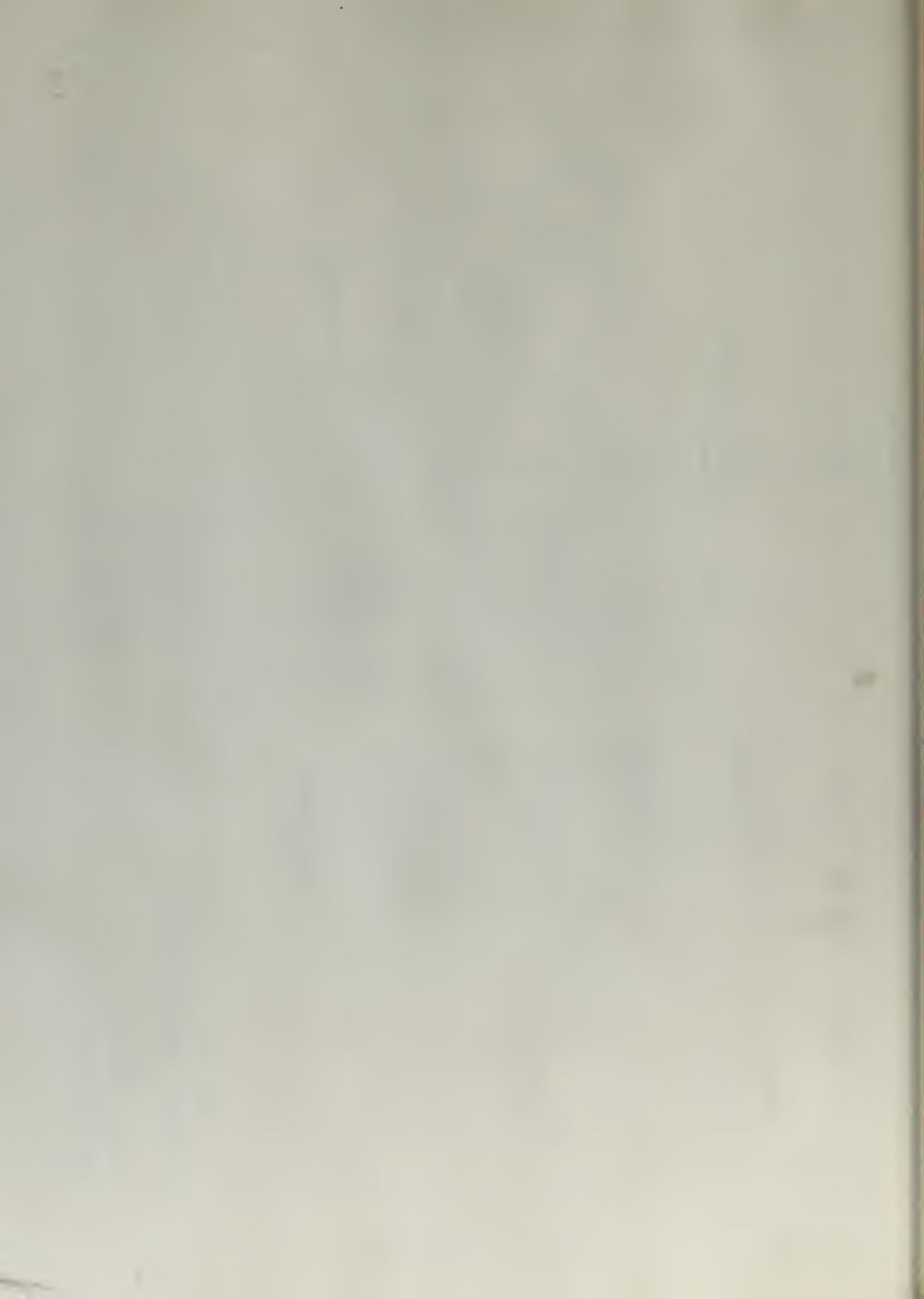






Fig. 3

CFR Engine Piston  
PLAIN PISTON

By the author of "The CFR Engine"

Fig. 3  
Train Plot

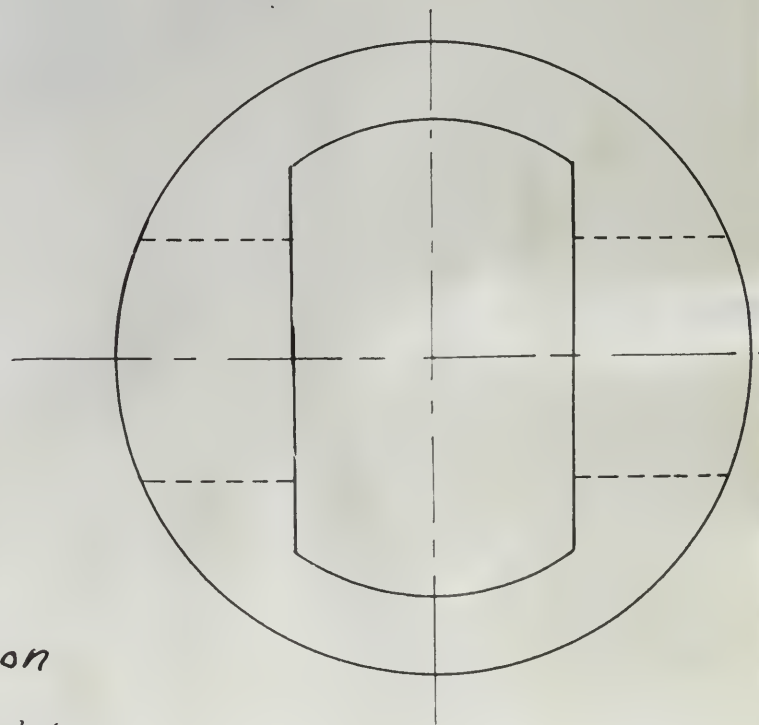
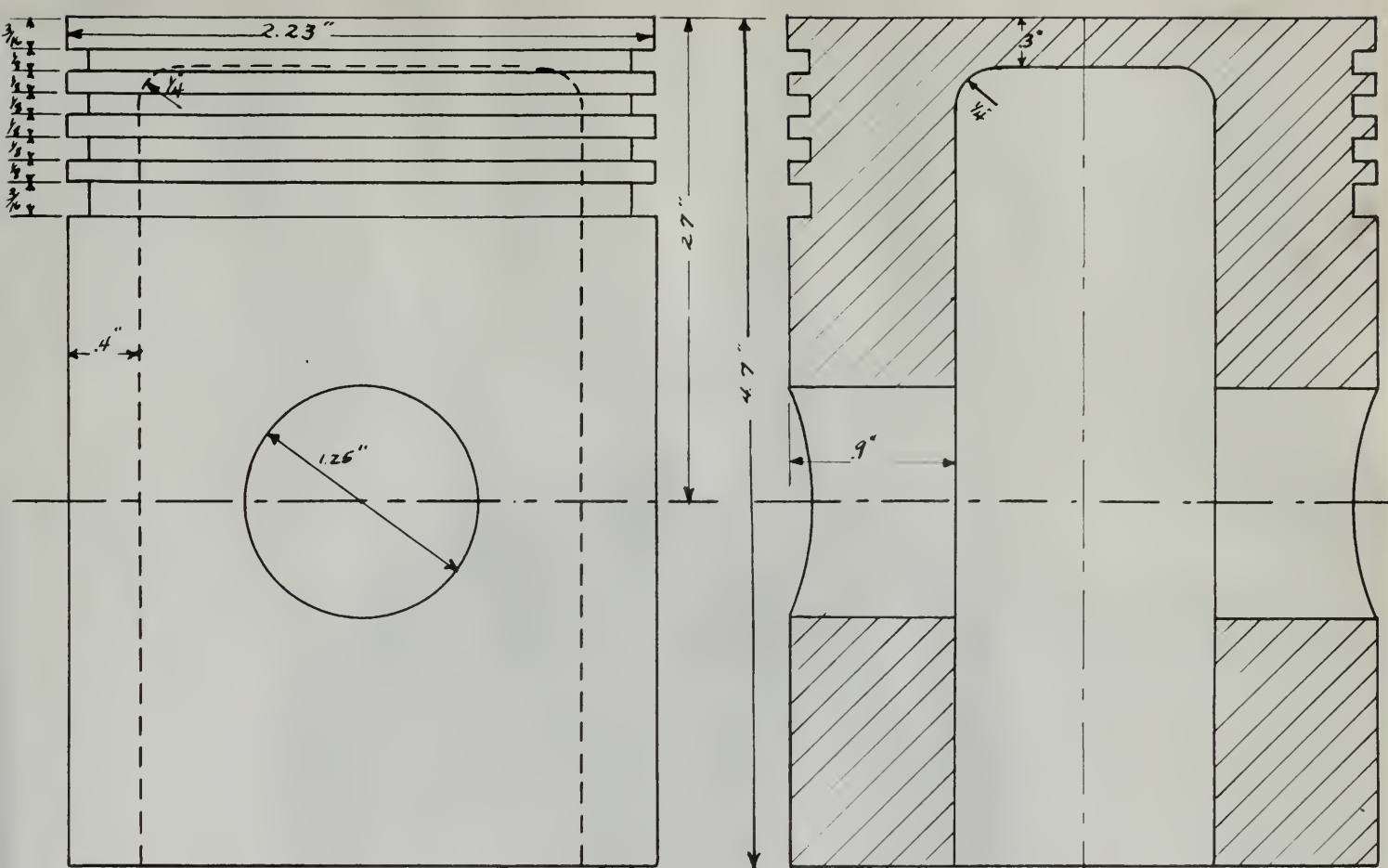


FIG. 4

C.F.R. Engine Piston

Lt. Com. J. H. Smith, Jr. & Lt. Com. N. O. Wittmann

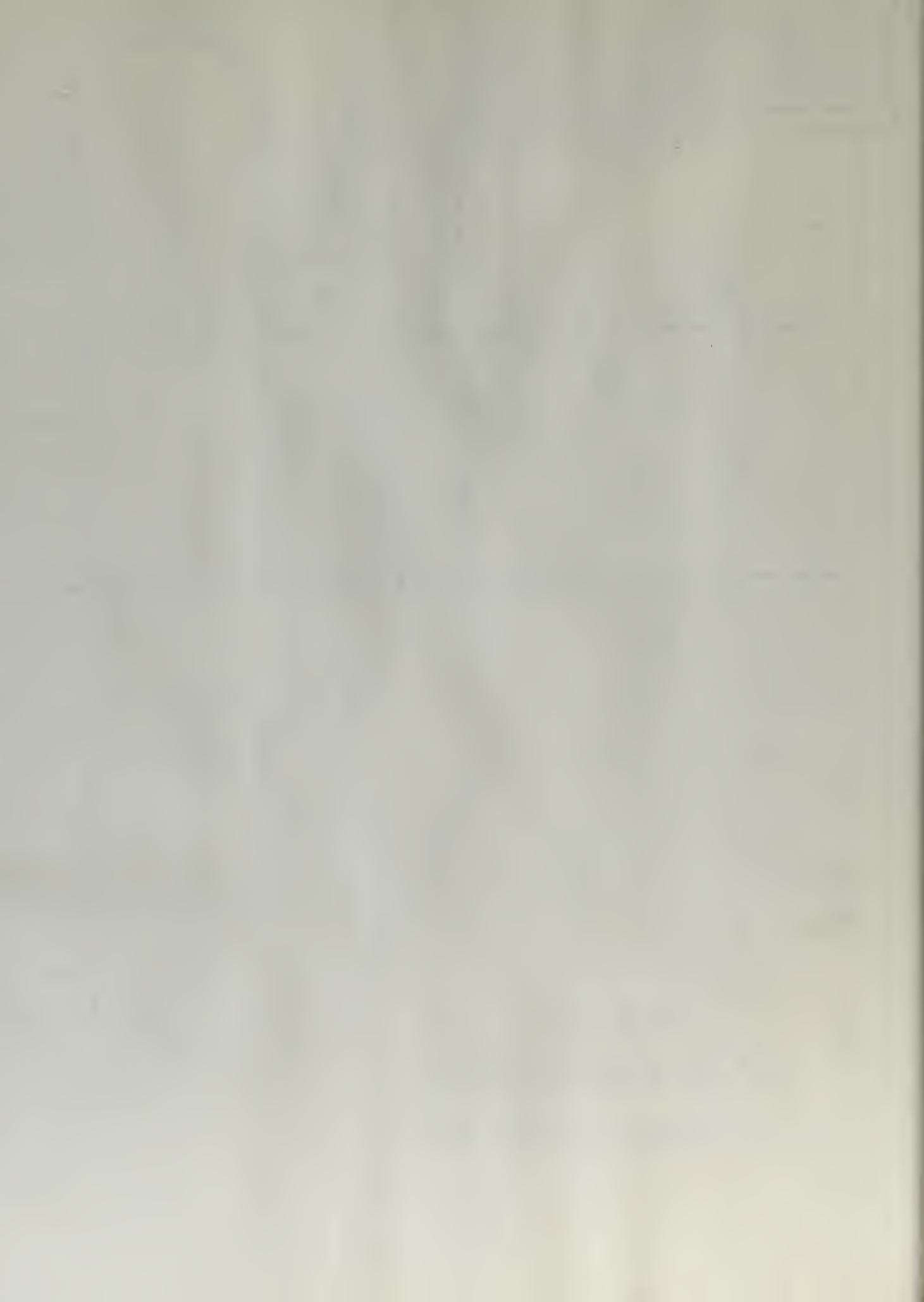






FIG. 5  
RIBBED PISTON



2, 217  
Hester Prynne



FIG. 7  
C.F.R. Engine Piston  
With Deep Fin

FIG. 6  
FINNED PISTON

20 Gears of 20 Tooth per inch 20 inch 20 inch 20 inch



Finned Pecten  
Fig. 6





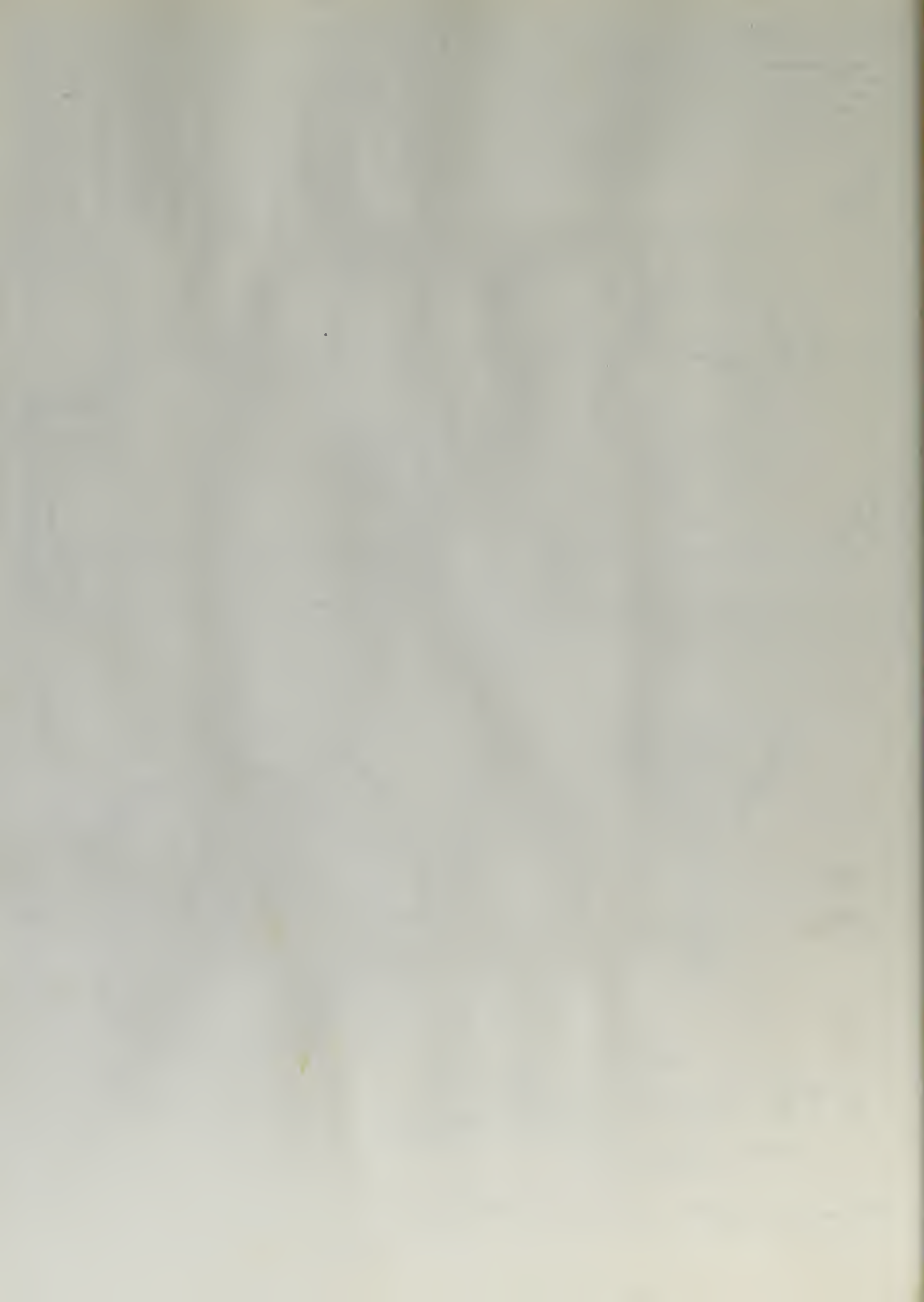




Figure 100 - (a) - (b) - (c) - (d) - (e) - (f) - (g) - (h) - (i) - (j) - (k) - (l) - (m) - (n) - (o) - (p) - (q) - (r) - (s) - (t) - (u) - (v) - (w) - (x) - (y) - (z) - (aa) - (ab) - (ac) - (ad) - (ae) - (af) - (ag) - (ah) - (ai) - (aj) - (ak) - (al) - (am) - (an) - (ao) - (ap) - (aq) - (ar) - (as) - (at) - (au) - (av) - (aw) - (ax) - (ay) - (az) - (ba) - (bb) - (bc) - (bd) - (be) - (bf) - (bg) - (bh) - (bi) - (bj) - (bk) - (bl) - (bm) - (bn) - (bo) - (bp) - (bq) - (br) - (bs) - (bt) - (bu) - (bv) - (bw) - (bx) - (by) - (bz) - (ca) - (cb) - (cc) - (cd) - (ce) - (cf) - (cg) - (ch) - (ci) - (cj) - (ck) - (cl) - (cm) - (cn) - (co) - (cp) - (cq) - (cr) - (cs) - (ct) - (cu) - (cv) - (cw) - (cx) - (cy) - (cz) - (da) - (db) - (dc) - (dd) - (de) - (df) - (dg) - (dh) - (di) - (dj) - (dk) - (dl) - (dm) - (dn) - (do) - (dp) - (dq) - (dr) - (ds) - (dt) - (du) - (dv) - (dw) - (dx) - (dy) - (dz) - (ea) - (eb) - (ec) - (ed) - (ee) - (ef) - (eg) - (eh) - (ei) - (ej) - (ek) - (el) - (em) - (en) - (eo) - 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(kc) - (kd) - (ke) - (kf) - (kg) - (kh) - (ki) - (kj) - (kk) - (kl) - (km) - (kn) - (ko) - (kp) - (kq) - (kr) - (ks) - (kt) - (ku) - (kv) - (kw) - (kx) - (ky) - (kz) - (la) - (lb) - (lc) - (ld) - (le) - (lf) - (lg) - (lh) - (li) - (lj) - (lk) - (ll) - (lm) - (ln) - (lo) - (lp) - (lq) - (lr) - (ls) - (lt) - (lu) - (lv) - (lw) - (lx) - (ly) - (lz) - (ma) - (mb) - (mc) - (md) - (me) - (mf) - (mg) - (mh) - (mi) - (mj) - (mk) - (ml) - (mm) - (mn) - (mo) - (mp) - (mq) - (mr) - (ms) - (mt) - (mu) - (mv) - (mw) - (mx) - (my) - (mz) - (na) - (nb) - (nc) - (nd) - (ne) - (nf) - (ng) - (nh) - (ni) - (nj) - (nk) - (nl) - (nm) - (nn) - (no) - (np) - (nq) - (nr) - (ns) - (nt) - (nu) - (nv) - (nw) - (nx) - (ny) - (nz) - (oa) - (ob) - (oc) - (od) - (oe) - (of) - (og) - (oh) - (oi) - (oj) - (ok) - (ol) - (om) - (on) - (oo) - (op) - (oq) - (or) - (os) - (ot) - (ou) - (ov) - (ow) - (ox) - (oy) - (oz) - (pa) - (pb) - (pc) - (pd) - (pe) - (pf) - (pg) - (ph) - (pi) - (pj) - (pk) - (pl) - (pm) - (pn) - (po) - 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(S) - (T) - (U) - (V) - (W) - (X) - (Y) - (Z) - (AA) - (AB) - (AC) - (AD) - (AE) - (AF) - (AG) - (AH) - (AI) - (AJ) - (AK) - (AL) - (AM) - (AN) - (AO) - (AP) - (AQ) - (AR) - (AS) - (AT) - (AU) - (AV) - (AW) - (AX) - (AY) - (AZ) - (BA) - (BB) - (BC) - (BD) - (BE) - (BF) - (BG) - (BH) - (BI) - (BJ) - (BK) - (BL) - (BM) - (BN) - (BO) - (BP) - (BQ) - (BR) - (BS) - (BT) - (BU) - (BV) - (BW) - (BX) - (BY) - (BZ) - (CA) - (CB) - (CC) - (CD) - (CE) - (CF) - (CG) - (CH) - (CI) - (CJ) - (CK) - (CL) - (CM) - (CN) - (CO) - (CP) - (CQ) - (CR) - (CS) - (CT) - (CU) - (CV) - (CW) - (CX) - (CY) - (CZ) - (DA) - (DB) - (DC) - (DD) - (DE) - (DF) - (DG) - (DH) - (DI) - (DJ) - (DK) - (DL) - (DM) - (DN) - (DO) - (DP) - (DQ) - (DR) - (DS) - (DT) - (DU) - (DV) - (DW) - (DX) - (DY) - (DZ) - (EA) - (EB) - (EC) - (ED) - (EE) - (EF) - (EG) - (EH) - (EI) - (EJ) - (EK) - (EL) - (EM) - (EN) - (EO) - (EP) - (EQ) - (ER) - (ES) - (ET) - (EU) - (EV) - (EW) - (EX) - (EY) - (EZ) - (FA) - (FB) - (FC) - (FD) - (FE) - (FF) - (FG) - (FH) - (FI) - (FJ) - (FK) - (FL) - (FM) - (FN) - (FO) - (FP) - (FQ) - (FR) - (FS) - (FT) - (FU) - (FV) - (FW) - (FX) - (FY) - (FZ) - (GA) - (GB) - (GC) - (GD) - (GE) - (GF) - (GG) - (GH) - (GI) - (GJ) - (GK) - (GL) - (GM) - (GN) - (GO) - (GP) - (GQ) - (GR) - (GS) - (GT) - (GU) - (GV) - (GW) - (GX) - (GY) - (GZ) - (HA) - (HB) - (HC) - (HD) - (HE) - (HF) - (HG) - (HH) - (HI) - (HJ) - (HK) - (HL) - (HM) - (HN) - (HO) - (HP) - (HQ) - (HR) - (HS) - (HT) - (HU) - (HV) - (HW) - (HX) - (HY) - (HZ) - (IA) - (IB) - (IC) - (ID) - (IE) - (IF) - (IG) - (IH) - (II) - (IJ) - (IK) - (IL) - (IM) - (IN) - (IO) - (IP) - (IQ) - (IR) - (IS) - (IT) - (IU) - (IV) - (IW) - (IX) - (IY) - (IZ) - (JA) - (JB) - (JC) - (JD) - (JE) - (JF) - (JG) - (JH) - (JI) - (JJ) - (JK) - (JL) - (JM) - (JN) - (JO) - (JP) - (JQ) - (JR) - (JS) - (JT) - (JU) - (JV) - (JW) - (JX) - (JY) - (JZ) - (KA) - (KB) - (KC) - (KD) - (KE) - (KF) - (KG) - (KH) - (KI) - (KJ) - (KK) - (KL) - (KM) - (KN) - (KO) - (KP) - (KQ) - (KR) - (KS) - (KT) - (KU) - (KV) - (KW) - (KX) - (KY) - (KZ) - (LA) - (LB) - (LC) - (LD) - (LE) - (LF) - (LG) - (LH) - (LI) - (LJ) - (LK) - (LL) - (LM) - (LN) - (LO) - (LP) - (LQ) - (LR) - (LS) - (LT) - (LU) - (LV) - (LW) - (LX) - (LY) - (LZ) - (MA) - (MB) - (MC) - (MD) - (ME) - (MF) - (MG) - (MH) - (MI) - (MJ) - (MK) - (ML) - (MM) - (MN) - (MO) - (MP) - (MQ) - (MR) - (MS) - (MT) - (MU) - (MV) - (MW) - (MX) - (MY) - (MZ) - (NA) - (NB) - (NC) - (ND) - (NE) - (NF) - (NG) - (NH) - (NI) - (NJ) - (NK) - (NL) - (NM) - (NN) - (NO) - (NP) - (NQ) - (NR) - (NS) - (NT) - (NU) - (NV) - (NW) - (NX) - (NY) - (NZ) - (OA) - (OB) - (OC) - (OD) - (OE) - (OF) - (OG) - (OH) - (OI) - (OJ) - (OK) - (OL) - (OM) - (ON) - (OO) - (OP) - (OQ) - (OR) - (OS) - (OT) - (OU) - (OV) - (OW) - (OX) - (OY) - (OZ) - (PA) - (PB) - (PC) - (PD) - (PE) - (PF) - (PG) - (PH) - (PI) - (PJ) - (PK) - (PL) - (PM) - (PN) - (PO) - (PP) - (PQ) - (PR) - (PS) - (PT) - (PU) - (PV) - (PW) - (PX) - (PY) - (PZ) - (QA) - (QB) - (QC) - (QD) - (QE) - (QF) - (QG) - (QH) - (QI) - (QJ) - (QK) - (QL) - (QM) - (QN) - (QO) - (QP) - (QQ) - (QR) - (QS) - (QT) - (QU) - (QV) - (QW) - (QX) - (QY) - (QZ) - (RA) - (RB) - (RC) - (RD) - (RE) - (RF) - (RG) - (RH) - (RI) - (RJ) - (RK) - (RL) - (RM) - (RN) - (RO) - (RP) - (RQ) - (RR) - (RS) - (RT) - (RU) - (RV) - (RW) - (RX) - (RY) - (RZ) - (SA) - (SB) - (SC) - (SD) - (SE) - (SF) - (SG) - (SH) - (SI) - (SJ) - (SK) - (SL) - (SM) - (SN) - (SO) - (SP) - (SQ) - (SR) - (SS) - (ST) - (SU) - (SV) - (SW) - (SX) - (SY) - (SZ) - (TA) - (TB) - (TC) - (TD) - (TE) - (TF) - (TG) - (TH) - (TI) - (TJ) - (TK) - (TL) - (TM) - (TN) - (TO) - (TP) - (TQ) - (TR) - (TS) - (TT) - (TU) - (TV) - (TW) - (TX) - (TY) - (TZ) - (UA) - (UB) - (UC) - (UD) - (UE) - (UF) - (UG) - (UH) - (UI) - (UJ) - (UK) - (UL) - (UM) - (UN) - (UO) - (UP) - (UQ) - (UR) - (US) - (UT) - (UU) - (UV) - (UW) - (UX) - (UY) - (UZ) - (VA) - (VB) - (VC) - (VD) - (VE) - (VF) - (VG) - (VH) - (VI) - (VJ) - (VK) - (VL) - (VM) - (VN) - (VO) - (VP) - (VQ) - (VR) - (VS) - (VT) - (VU) - (VV) - (VW) - (VX) - (VY) - (VZ) - (WA) - (WB) - (WC) - (WD) - (WE) - (WF) - (WG) - (WH) - (WI) - (WJ) - (WK) - (WL) - (WM) - (WN) - (WO) - (WP) - (WQ) - (WR) - (WS) - (WT) - (WU) - (WV) - (WW) - (WX) - (WY) - (WZ) - (XA) - (XB) - (XC) - (XD) - (XE) - (XF) - (XG) - (XH) - (XI) - (XJ) - (XK) - (XL) - (XM) - (XN) - (XO) - (XP) - (XQ) - (XR) - (XS) - (XT) - (XU) - (XV) - (XW) - (XX) - (XY) - (XZ) - (YA) - (YB) - (YC) - (YD) - (YE) - (YF) - (YG) - (YH) - (YI) - (YJ) - (YK) - (YL) - (YM) - (YN) - (YO) - (YP) - (YQ) - (YR) - (YS) - (YT) - (YU) - (YV) - (YW) - (YX) - (YY) - (YZ) - (ZA) - (ZB) - (ZC) - (ZD) - (ZE) - (ZF) - (ZG) - (ZH) - (ZI) - (ZJ) - (ZK) - (ZL) - (ZM) - (ZN) - (ZO) - (ZP) - (ZQ) - (ZR) - (ZS) - (ZT) - (ZU) - (ZV) - (ZW) - (ZX) - (ZY) - (ZZ)



Fig 8  
Take Off Switch Bracket



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# PLAIN PISTON

REV. PER MINUTE	T <sub>w</sub> (°F)	RUN #1 PISTON TEMP (°F)	RUN #2 PISTON TEMP (°F)	RUN #3 PISTON TEMP (°F)	RUN #4 PISTON TEMP (°F)	PISTON TEMP (WITH OIL) (°F)	PISTON TEMP (WITH OIL) (°F)
800	90	248	255	258	246	203	202
"	150	282	291	298	283	222	232
"	210	323	325	328	326	245	260
1000	90	267	265	275	255	218	220
"	150	298	302	295	297	236	242
"	210	333	347	351	346	261	270
1200	90	275	282	285	272	244	225
"	150	310	312	321	318	250	257
"	210	340	348	342	351	261	270

# RIBBED PISTON

800	90	275	257	259		198	
"	150	312	303	297		215	
"	210	352	347	343		234	
1000	90	286	265	267		187	
"	150	320	287	287		215	
"	210	358	345	342		226	
1200	90	299	277	282		207	
"	150	329	312	315		207	
"	210	370	347	351		235	

# FINNED PISTON

800	90	308	288	270		175	
"	150	340	330	312		175	
"	210	372	352	349		175	
1000	90	318	312	310		185	
"	150	344	341	342		198	
"	210	382	370	365		202	
1200	90	328	330	318		200	
"	150	358	365	345		202	
"	210	380	370	365		195	

$F/A = .08$

$T_k = 150^\circ F$

TABLE I

$T_0 = 80^\circ F$

$P_0 = 49 \text{ lb/in}^2$

VARIATION OF PISTON TEMPERATURE  
WITH RPM AND WATER JACKET TEMPERATURE

FUEL AIR RATIO	PISTON TEMP	FUEL AIR RATIO	PISTON TEMP	INLET TEMP	PISTON TEMP
.055	255	.10	312	105	328
.06	278	.11	298	120	328
.07	306	.12	285	140	331
.08	325	.13	275	160	332
.09	320	.14	271	174	331

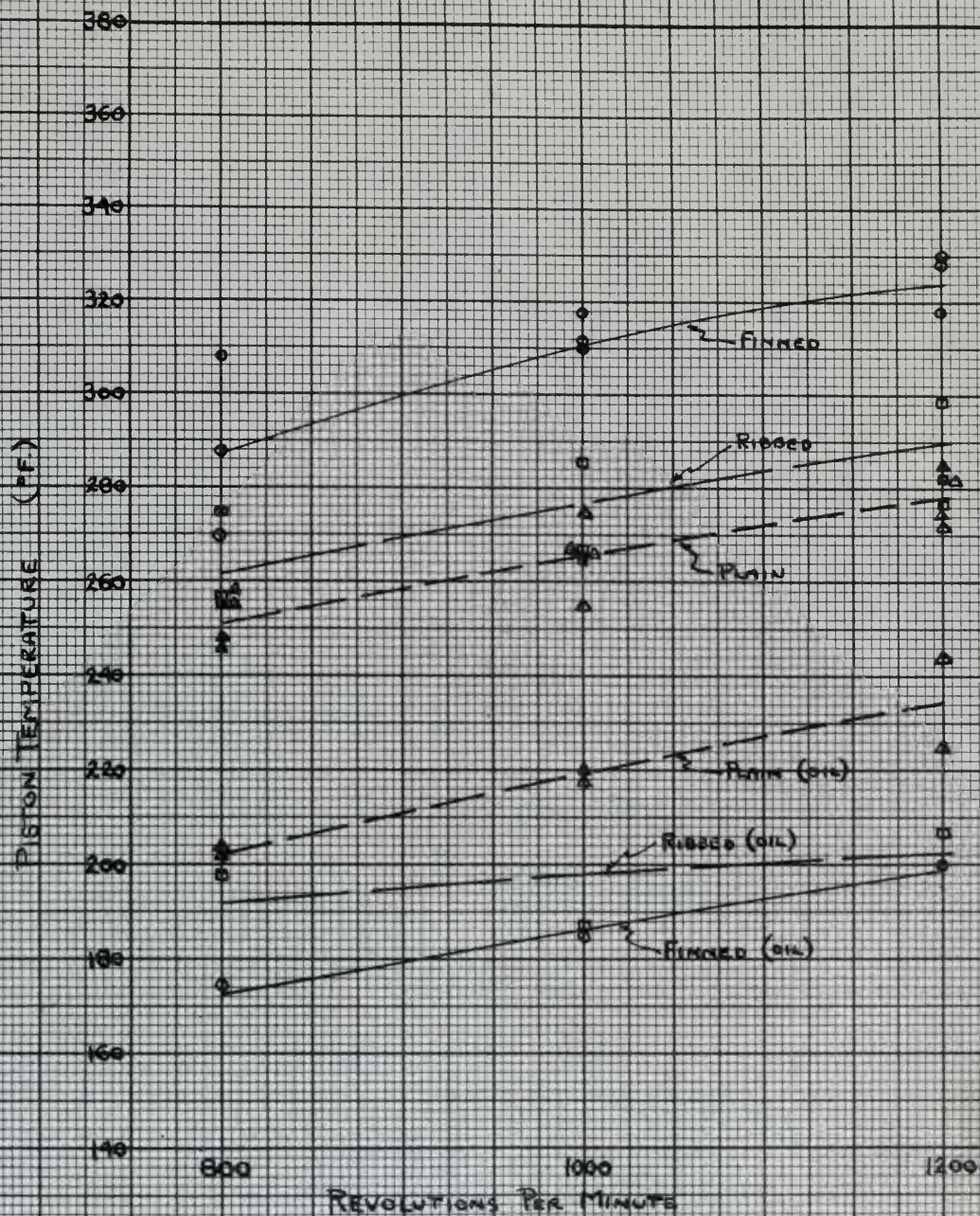
TABLE II  
VARIATION OF PISTON TEMPERATURE  
WITH FUEL AIR RATIO

TABLE III  
VARIATION OF PISTON TEMPERATURE  
WITH INLET TEMPERATURE









$T_w = 90^\circ\text{F}$

$F/A = .03$   $T_w = 90^\circ\text{F}$   $T_c = 150^\circ\text{F}$   $T_a = 90^\circ\text{F}$   $p = 50 \text{ lb/in}^2$   $D = 10.714 \text{ in}^3$

FIG. 9

VARIATION OF PISTON TEMPERATURE  
WITH RPM FOR THREE TYPES OF  
PISTONS - SHOWING EFFECT OF OIL STREAM

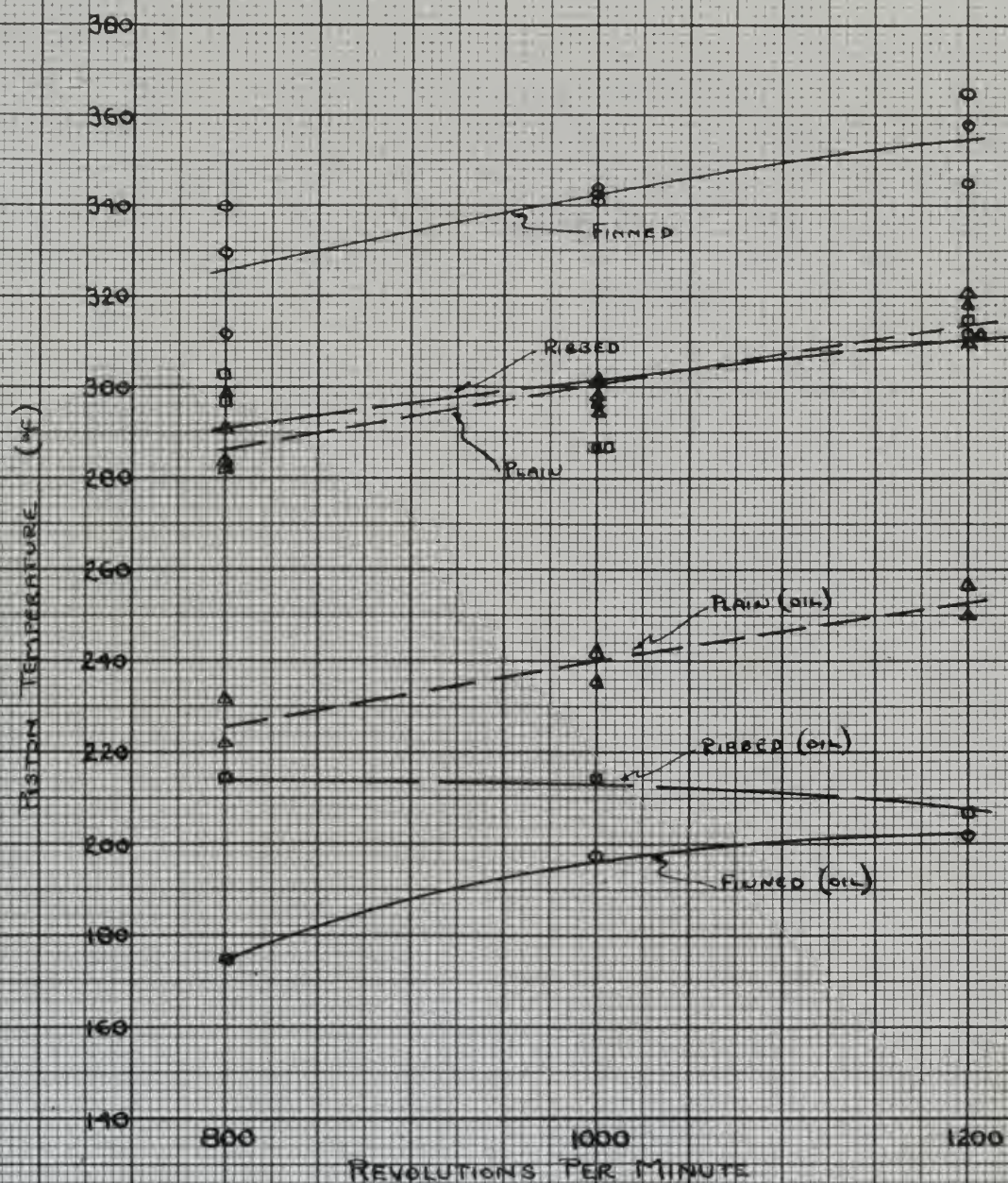
GAS H.O.W.

4-21-46









$T_w = 150^\circ\text{F}$

$R/A = .08$   $T_c = 150^\circ\text{F}$   $T_o = 30^\circ\text{F}$   $p_o = 50 \text{ lb/in}^2$   $p_c = 10.7 \text{ lb/in}^2$

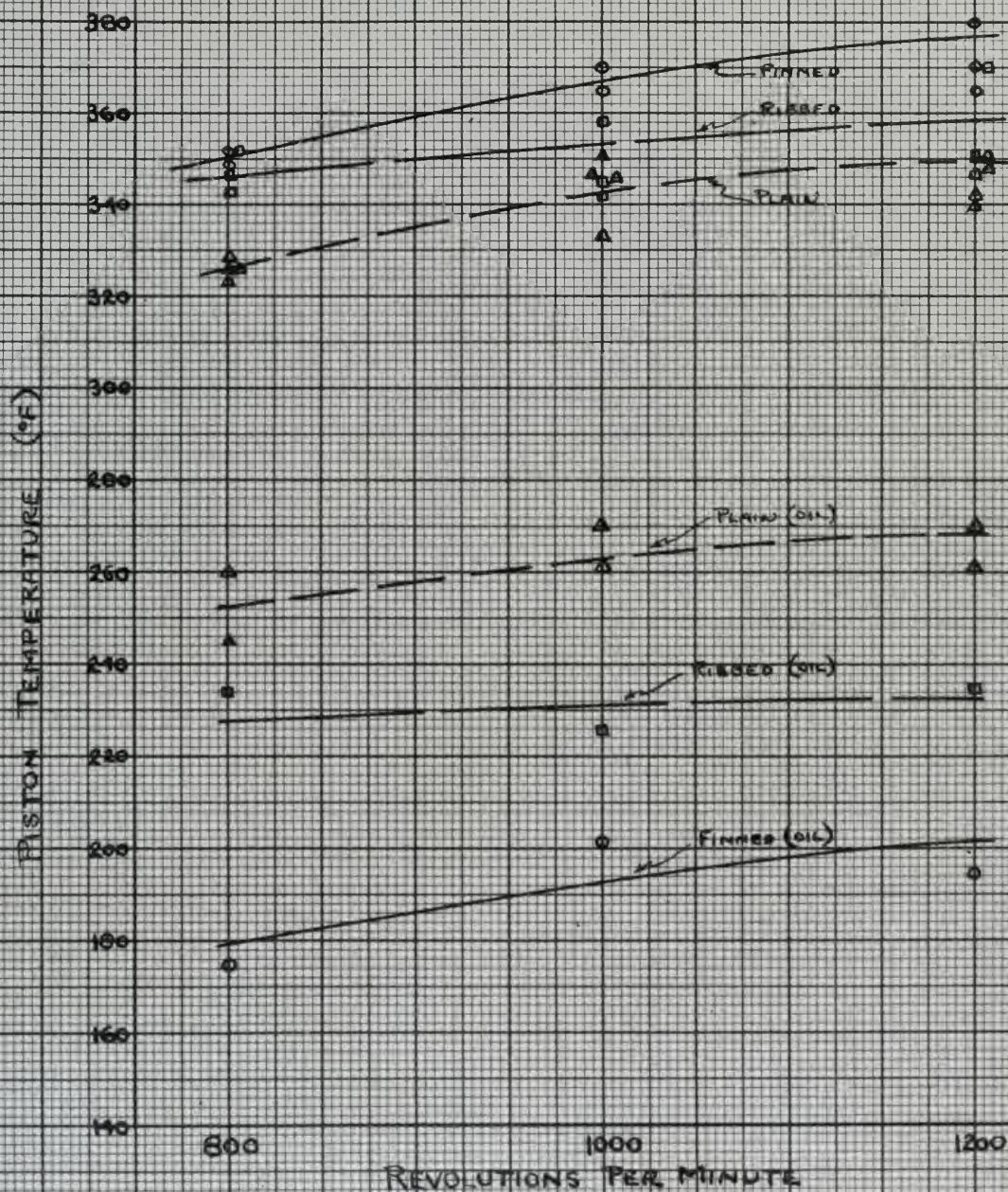
FIG. 10

VARIATION OF PISTON TEMPERATURE  
WITH R.P.M. FOR THREE TYPES OF  
PISTONS - SHOWING EFFECT OF OIL STREAM  
JAS H.O.W. 4-27-46









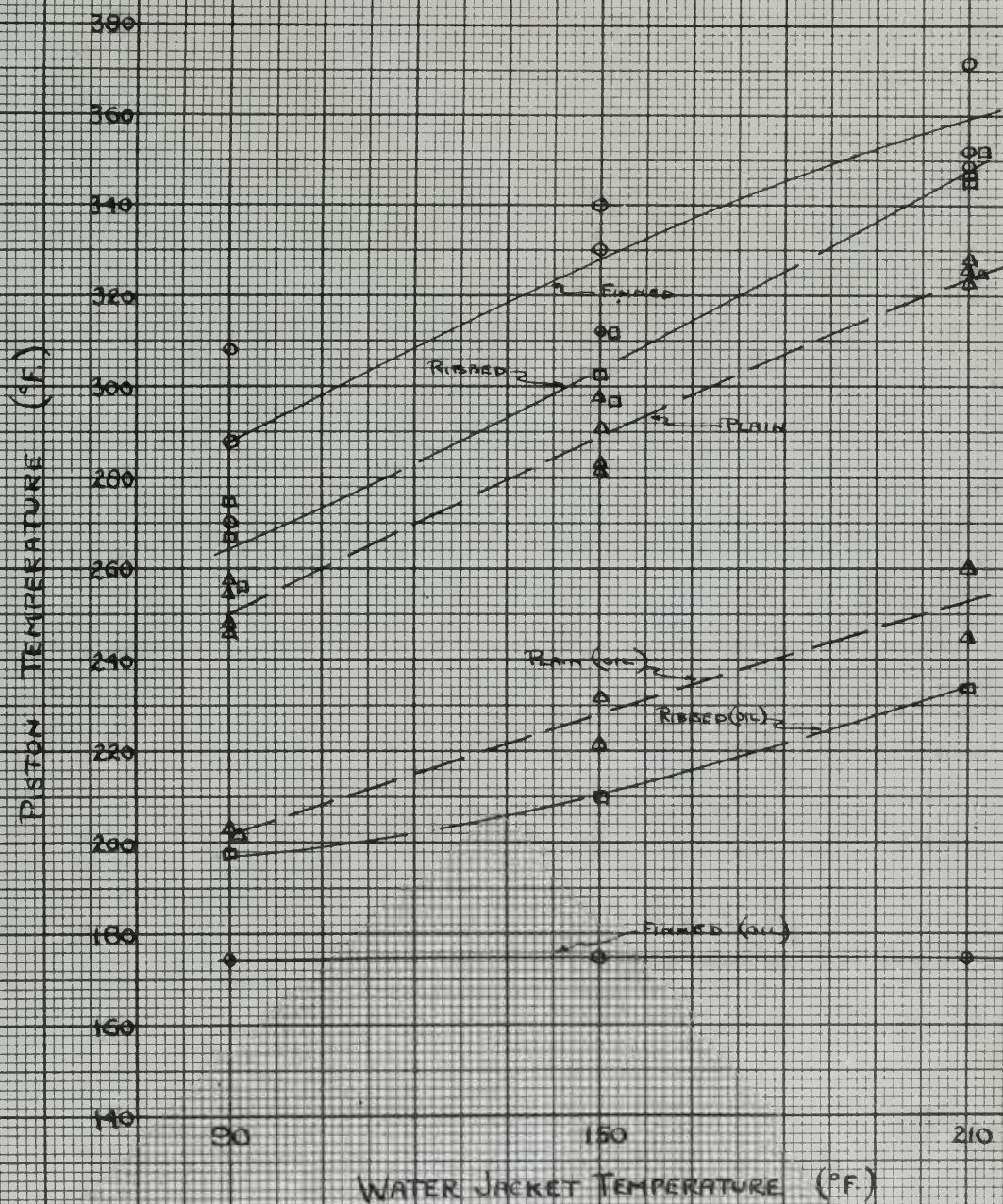
$T_w = 210^\circ\text{F}$   
 $F/A = .08$   $T_o = 150^\circ\text{F}$   $T_s = 30^\circ\text{F}$   $p_o = 50 \text{ lb/in}^2$   $p_r = 10.7 \text{ lb/in}^2$

**FIG. 11**  
 VARIATION OF PISTON TEMPERATURE  
 WITH R.P.M. FOR THREE TYPES OF PISTONS  
 SHOWING EFFECT OF OIL STREAM  
 YES NOW 4-27-76









RPM = 800  
 $F/A = .08$   $T_c = 150^\circ\text{F}$   $T_o = 30^\circ\text{F}$   $p_o = 50 \text{ lb/in}^2$   $R = 10.7 \text{ lb/in}^2$

FIG. 12

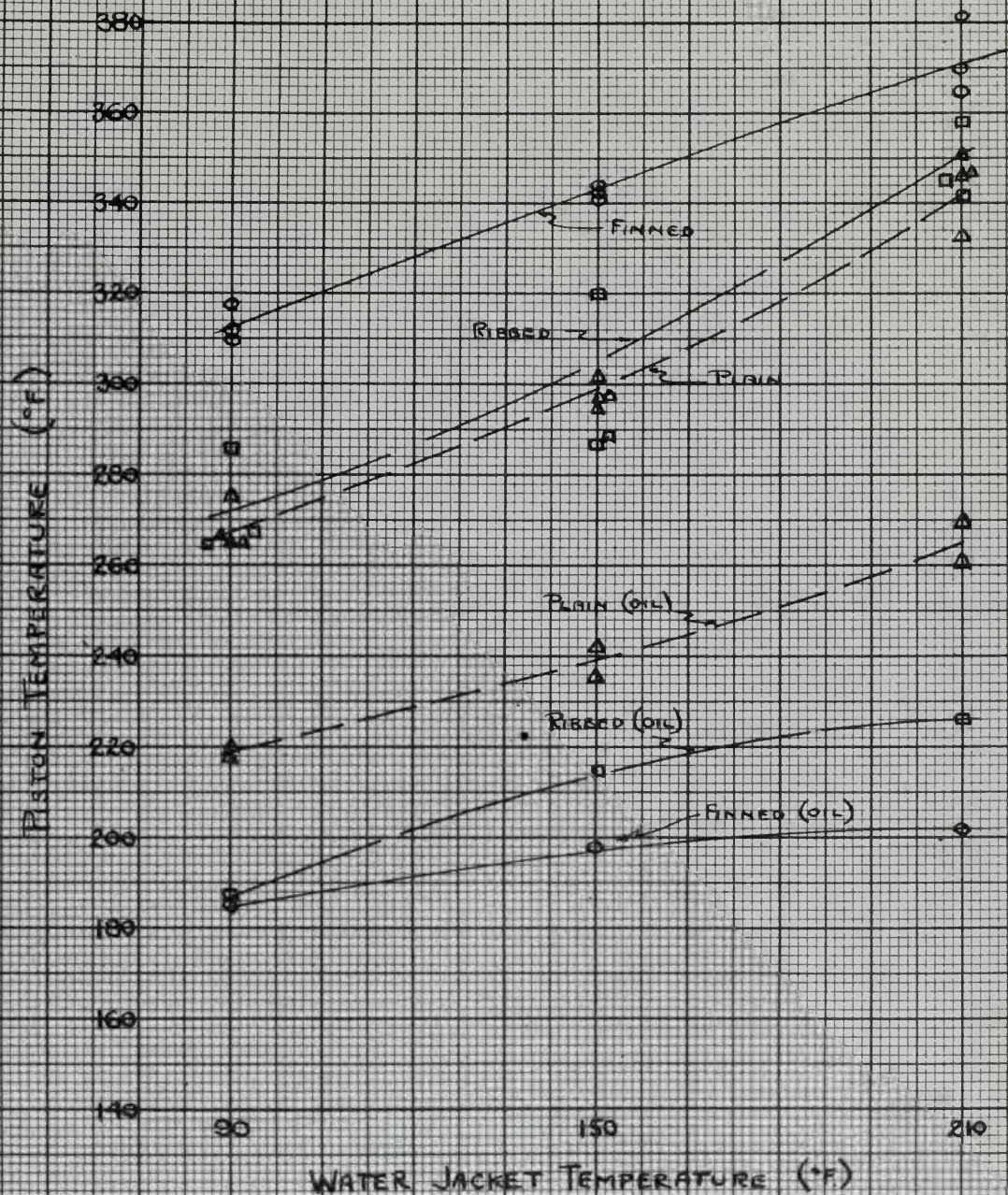
VARIATION OF PISTON TEMPERATURE  
 WITH WATER JACKET TEMPERATURE  
 FOR THREE TYPES OF PISTONS  
 SHOWING EFFECT OF OIL STREAM

JOS T.O.W.

4-27-46







RPM = 1000  
 $F/A = .08$   $T_c = 150^\circ\text{F}$   $T_o = 30^\circ\text{F}$   $p_c = 50 \text{ lb/in}^2$   $p_o = 10.7 \text{ lb/in}^2$

FIG. 13

VARIATION OF PISTON TEMPERATURE  
 WITH WATER JACKET TEMPERATURE  
 FOR THREE TYPES OF PISTONS  
 SHOWING EFFECT OF OIL STREAM

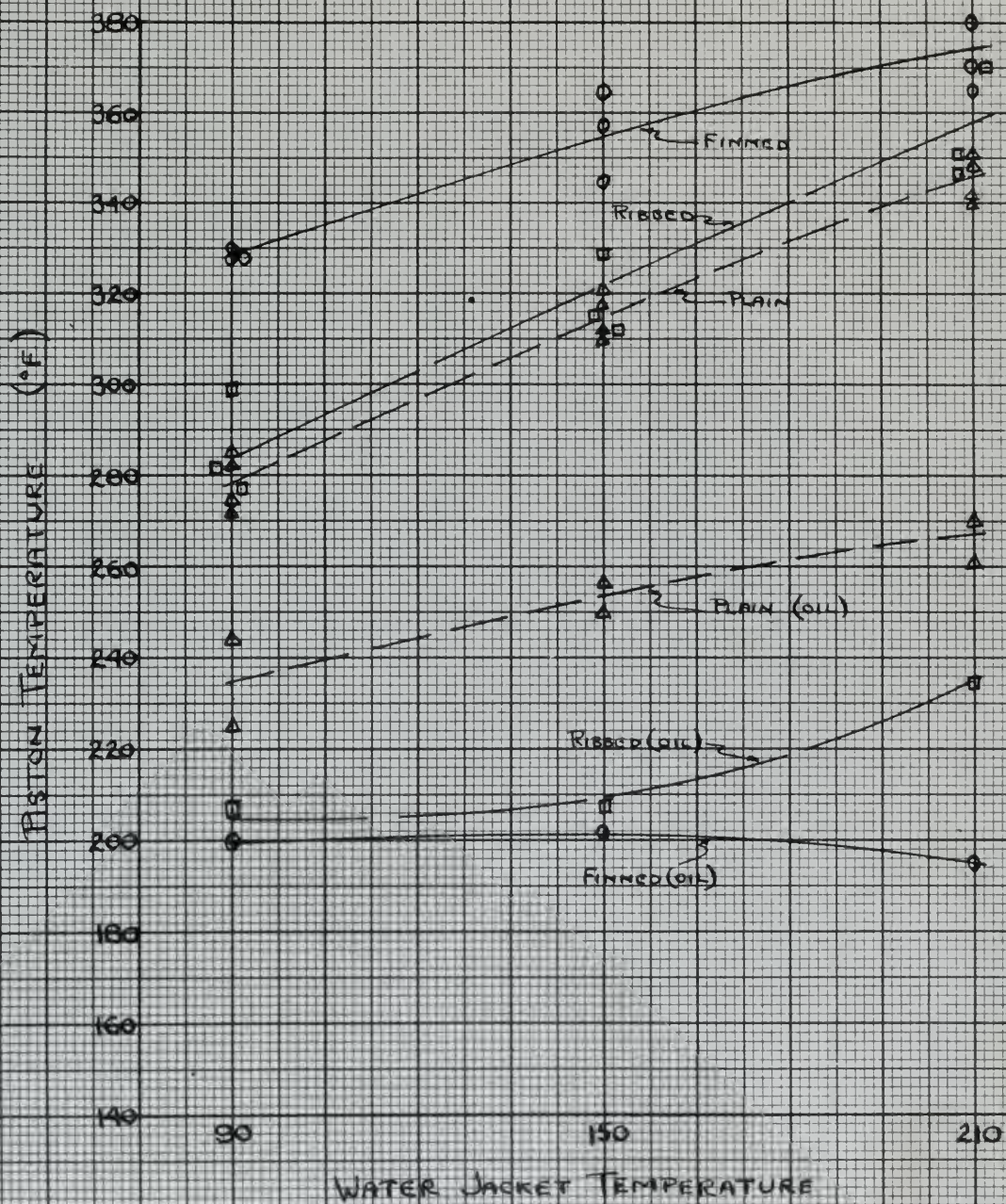
JAS. H. O. W.

4-23-46









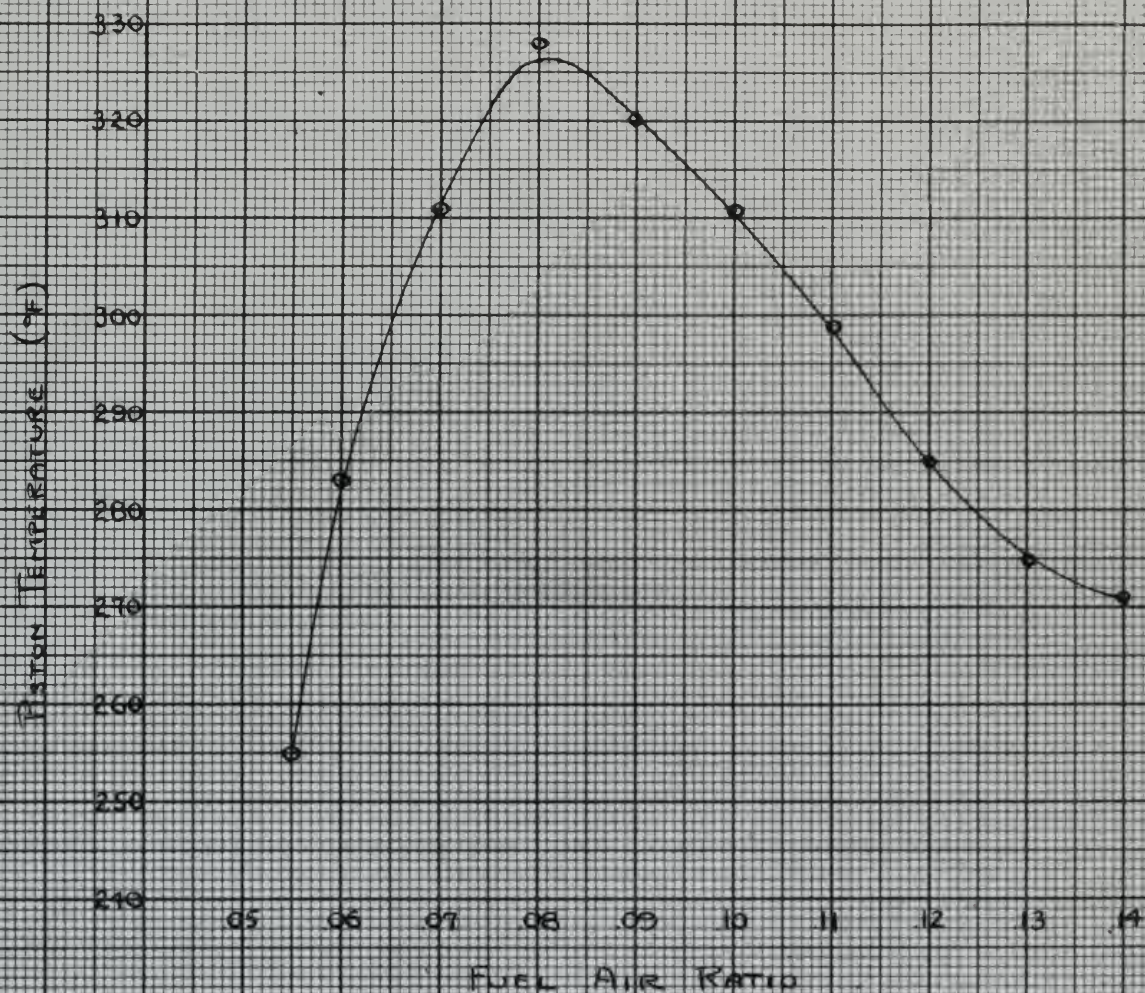
$F/A = .08$      $T_c = 150^\circ\text{F}$      $T_o = 90^\circ\text{F}$      $P_o = 50 \text{ lb/in}^2$      $P_c = 10.7 \text{ lb/in}^2$   
 $\text{RPM} = 1200$

**FIG 14**  
 VARIATION OF PISTON TEMPERATURE  
 WITH WATER JACKET TEMPERATURE  
 FOR THREE TYPES OF PISTONS  
 SHOWING EFFECT OF OIL STREAM  
 JES N.O.W.    4-27-46

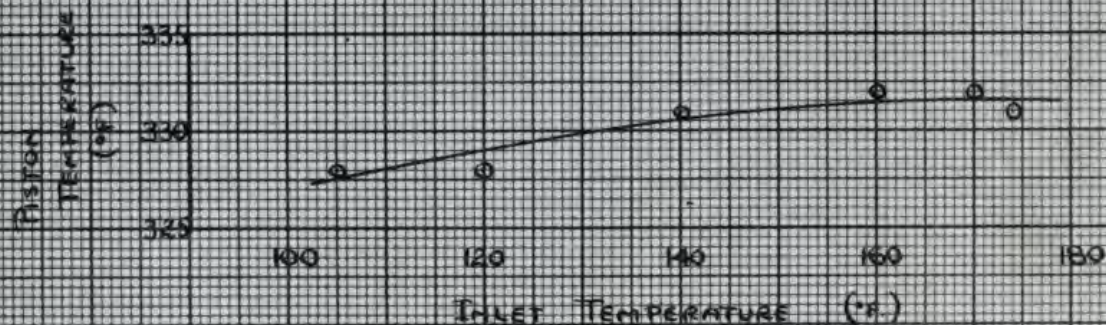








$T_i = 130^\circ\text{F}$      $T_w = 150^\circ\text{F}$     R.P.M. = 1200     $T_o = 90^\circ\text{F}$      $p_a = 50 \text{ lb/in}^2$      $p_k = 10.7 \text{ lb/in}^2$   
 RIBBED PISTON



$F/A = 0.8$      $T_w = 150^\circ\text{F}$     R.P.M. = 1200     $T_o = 90^\circ\text{F}$      $p_a = 50 \text{ lb/in}^2$      $p_k = 10.7 \text{ lb/in}^2$   
 RIBBED PISTON

FIG 15

VARIATION OF PISTON TEMPERATURE  
 WITH FUEL AIR RATIO AND INLET TEMPERATURE

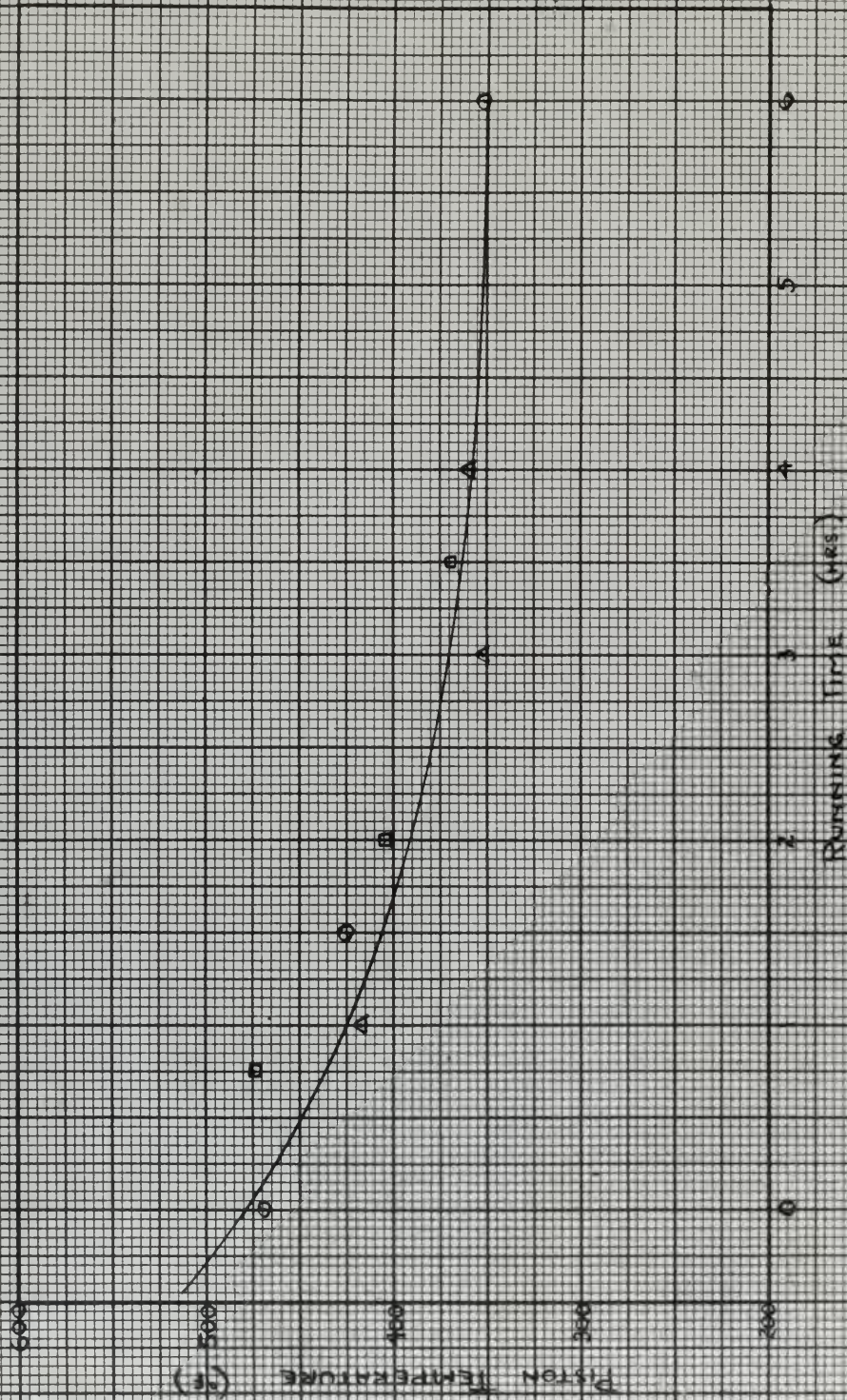
JES Now

4-26-46









$T_c = 150^\circ\text{F}$   
 $T_w = 150^\circ\text{F}$   
 $F/A = .08$   
 $\text{Finned Piston}$   
 $RPM = 1000$   
 $T_c = 90^\circ\text{F}$   
 $P_c = 50.14 \text{ (in.)}$   
 $P_f = 10.7 \text{ (in.)}$

FIG. 16

PISTON TEMPERATURE VARIATION WITH  
 RING WEAR IN WHEN RING 'Blow By'  
 WAS IN EVIDENCE

JES NOW  
 4-27-46



















## DATE DUE

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